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LITTER DECOMPOSITION AND CLIMATE - REGIONAL AND LOCAL MODELS

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Abstract

The climatic influence on plant litter decomposition has been successfully correlated on a regional level by using estimated actual evapotranspiration (AET) and annual weight loss. This approach was applied to decomposition studies carried out in a transect along Sweden with litter incubated in different forest types. A unified litter was used and among 14 Scots pine sites about 90 per cent of the weight loss rate could be explained by this approach which consequently appeared to be useful on this level.

An attempt was also made with the same technique to explain annual variation at just one site (Scots pine forest) where annual incubations had been made for six years. The fit between AET and annual weight loss was significant on the 5 per cent level in this case. However, at the same site soil moisture and temperature were estimated with the aid of a physical soil water and heat model. These estimated soil variables were correlated with weight loss of litter. In this attempt about 95 to 99 per cent of the weight loss could be explained by climatic factors.

Experimental approaches to analyse the climatic influence on decomposition are now made both on the regional and the local scale. For the regional scale unified Scots pine needles were incubated in the same type of nutrient poor Scots pine forest on sediment with ten sites from northernmost Finland (69°N, 27°E) to southern Holland (52°N, E). The annual weight loss will be related to AET and to soil variables as predicted with the physically based soil water and heat model. Account should thus be taken for different canopy covers and soil properties.

INTRODUCTION

The release of nutrients from decomposing plant litter is a process which makes them available for root uptake and a key process for a forest's internal nutrient cycling. The final release may follow after an immobilization or after both a non-biological leaching and an immobilization (Berg and Staaf 1981). Very little is known about nutrient dynamics and the mechanisms for nutrient release from litter but empirical data indicate that once a net release of nutrients from litter has started it is proportional to litter weight loss. This observation has been made for the release of N, P, S, K, Ca, Mg, and Mn from needle litter (Staaf and Berg, 1982).

The litter decomposing microorganisms are dependent on temperature and moisture for their activity which determines the decomposition rate of litter. Other important factors are the litter's nutrient level and availability of the carbon source.

Even if litter often makes up only a small proportion of the organic soil layers and its decomposition rate is higher than that of humus and of partly humified litter its decomposition rate may still be a comparative measure between sites and possibly reflect the decomposition rate of both humus and far decomposed and humified litter. Several models for respiration which are dependent on moisture and temperature have been constructed from laboratory measurements whereas it seems that there are few such ones made from field data (cf Svensson, 1980). There are several problems connected to the construction of a soil respiration model from field data. Apart from good field registration of temperature and moisture conditions there are also problems connected with - for example - root respiration and determination of actual volumes of respiration flasks.

It appears that few attempts have been made to correlate field data of litter decomposition to soil temperature and moisture conditions. Regional climatic variables such as calculated actual evapotranspiration has been used with success to explain large scale variability (Meentemeyer, 1978) but the high between-year variation found at one site for litter decomposition in central Sweden could only partly be explained by such variables (V. Meentemeyer and B. Berg, unpublished data). Such models for predicting decomposition as an effects of temperature and moisture both on a local and a regional level would be useful for decomposition studies both for separating the effect of climatic factors from influences such as substrate quality, acid rain and pollution. It would also be a tool to explain between-year variation.

The aim of this report is to present and discuss work carried out what regards climate and litter weight loss on both a local and a regional basis, ongoing work and possible developments. The present report combines data from four separate studies carried out in Sweden and the designs of the study plots vary but the litter-bag incubations and determinations of weight loss are the same in the separate studies which makes them comparable. The incubation technique used is presented by Berg et al., (1982). In this context we used just one type of litter, namely brown needle litter sampled in the same stand and even if it was sampled in different autumns it had a chemical composition that was fairly constant between the years (Berg and Staaf, 1981b).

MATERIALS AND METHODS

Table 1. List of experimental plots in Scots pine, Lodgepole pine, Norway spruce and Birch forests giving locality and some vegetation data as well as 1st year weight loss of a unified litter (Scots pine needle litter, nitrogen 0.41 % and lignin 25.7 %.)

Site name	No	Lat/Long	Altitude m.a.s.l.	Tree species	Ground vegetation	First year weight loss % (SE)
Xtnakobbo	17	66°22'N; 20°02'E	405	Norway spruce	V. myrtillus, moss	25.5 (0.69)
Harads	14	66°08'N; 20°53'E	58	Scots pine	V. vitis idaea, lichens	12.7 (0.26)
Manjörv C	15	65°47'N; 20°37'E	135	Scots pine	V. vitis idaea, lichens	14.7 (0.49)
Manjörv D	16	65°47'N; 20°37'E	135	Scots pine	V. myrtillus, moss	21.2 (0.57)
Norråden	18	64°21'N; 19°46'E	260	Scots pine	V. myrtillus, moss	20.3 (0.60)
Jädraås	1A	60°49'N; 16°30'E	185	Scots pine	V. vitis-idaea, moss lichens	31.5 (0.68)
Anundberget	11	60°38'N; 13°37'E	400	1. Scots pine 2. Lodgepole pine	V. myrtillus, moss V. myrtillus, moss	31.4 (0.55) 31.3 (0.88)
Nyhusen	13	60°35'N; 13°34'E	435	1. Scots pine 2. Lodgepole pine	V. myrtillus, moss V. myrtillus, moss	31.0 (0.50) 31.4 (0.66)
Kappsjön	12	60°33'N; 13°44'E	375	1. Scots pine 2. Lodgepole pine	V. myrtillus, moss V. myrtillus, moss	30.6 (0.68) 31.8 (0.60)
Garpenberg	10	60°16'N; 16°15'E	185	1. Norway spruce 2. Birch	no understorey grass	25.8 (0.69) 27.5 (0.83)
Tomta	7	59°49'N; 16°33'E	63	1. Scots pine 2. Norway spruce	V. myrtillus, moss no understorey	38.4 (1.17) 27.0 (0.95)
Grythyttan	9	59°44'N; 14°34'E	220	1. Scots pine 2. Lodgepole pine	V. myrtillus, moss V. myrtillus, moss	33.2 (1.23) 29.2 (0.58)
Kungs Husby	8	59°31'N; 17°16'E	30	1. Scots pine 2. Norway spruce	V. myrtillus, moss, grass moss	38.9 (1.35) 33.1 (1.70)
Grensholm	5	58°33'N; 15°51'E	58	1. Scots pine 2. Norway spruce	grass, herbs no understorey	34.8 (1.49) 21.1 (1.10)
Remningstorp	6	58°28'N; 13°39'E	128	1. Scots pine 2. Norway spruce	V. myrtillus, moss V. myrtillus, moss, grass	42.9 (0.97) 28.1 (1.06)
Tönnersjöheden	3	56°42'N; 13°05'E	80	1. Norway spruce 2. Birch	no understorey grass	22.4 (0.79) 39.7 (0.72)
Måstocka	2	56°36'N; 13°15'E	135	1. Scots pine 2. Norway spruce	V. myrtillus, moss no understorey	42.4 (0.96) 28.2 (0.52)

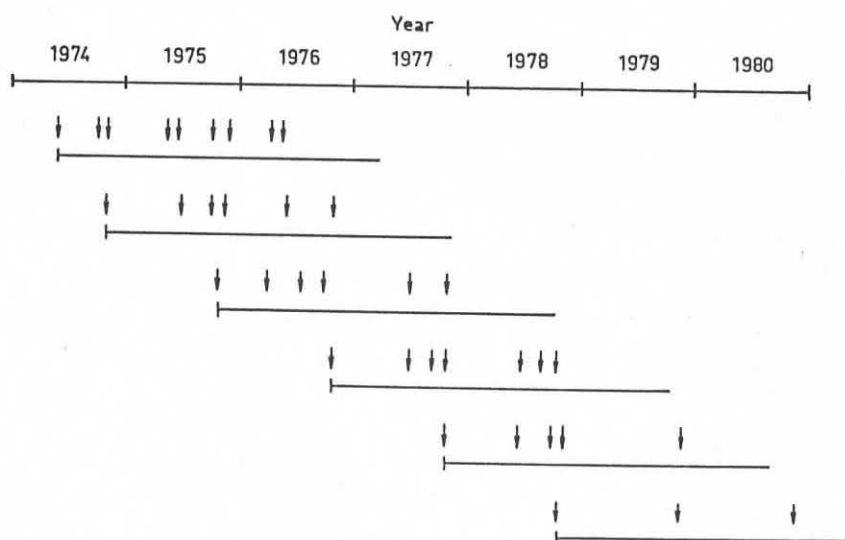
Site descriptions

A detailed site description for site 1 A (Swecon site) with regard to soil and stand properties is given by Axelsson and Bråkenhielm (1980). For the other sites some properties are given in Table 1.

Needle collection, storing, weighing and field incubations

These parts are described by Berg et al. (1982). Incubations were carried out in the spring of 1974 and the autumns of 1974-78. The litter-bags were fastened to the ground with the aid of metal pegs in their different plots. Samplings were made mainly three times a year at site 1A (Fig. 1) and once a year at sites 2-18 (Table 1). After collection the bags were stored at -20° until sample treatment took place. In this the needle litter was cleaned of ingrown moss and cowberry remnants, dried at 85° and the remaining weight was determined.

Figure 1. Overview of incubations and samplings (arrows) of Scots pine needle litter in the Scots pine forest stand at Jädraås.



Actual evapotranspiration (AET) model

Actual evapotranspiration was calculated by the method of Thornthwaite and Mather (1957). In all cases monthly temperature and precipitation were the only climatic variables extracted and tringulated from the weather data found in "Monthly and Yearly Summary of Weather and Water Supply in Sweden" (Swedish meteorological and hydrological institute, Norrköping, various dates).

The soil climatic model

This approach was made by the use of an abiotic soil model (SOIL) which simulated soil climate and a model for litter decomposition as dependent on soil temperature and moisture (SCM).

The abiotic SOIL model consists of the two coupled partial differential equations for heat and water which enable predictions of the soil climate at any level in the soil profile with appropriate soil properties and boundary conditions specified. A detailed description of the model is given by Jansson and Halldin, (1980). The model has previously been adapted to the 120-year-old Scots pine forest in Jädraås and tested against measurements of temperature, snow and frost depths, soil water content and tension (Jansson and Halldin, 1979).

For the present study the model was run for six full years and daily means of soil temperature, water content and tension were predicted representing the organic soil layer as a whole.

In the SCM approach the temperature effect on litter decomposition rate was tested with the equation:

$$D_T = Q_{10}^{(T-T_n)/10} \quad (1)$$

where D_T is a multiplicative factor for decomposition, Q_{10} is the steepness in the temperature function, T is actual soil temperature and T_n is the temperature for which D_T equals one.

The soil moisture effect was treated separately with expressions either of the unfrozen water content, (D_θ), or of the soil tension (D_ψ):

$$D_\theta = \begin{cases} (\theta/\theta_0)^a & \theta \leq \theta_0 \\ 1 & \theta > \theta_0 \end{cases} \quad (2)$$

$$D_\psi = \begin{cases} (\psi/\psi_0)^b & \psi \leq \psi_0 \\ 1 & \psi > \psi_0 \end{cases} \quad (3)$$

where θ is the volumetric water content, θ_0 is the threshold water content to achieve the optimal decomposition rate, ψ is the soil tension expressed in cm water, ψ_0 is the threshold soil tension to achieve the optimal decomposition rate and a and b are empirical constant.

Litter weight loss was expressed as the daily mean rate in per cent of the total mass of litter in the beginning of each subperiod from which measurements existed. These values of decomposition rates were compared with different abiotic functions such as the products of D_T and D_θ or D_T and D_ψ and with the mean actual evapotranspiration. The relationships between the decomposition rates and the abiotic functions were fitted to linear equations and the coefficients of determinations were used as a measure of goodness. The sensitivity for a number of different values of Q_{10} , θ_0 , a , ψ_0 and b were tested, on these coefficients of determination. The data set was used with either the first year decomposition values only, those of the second year or of both years together.

In a first step only decomposition data for periods of at least 4 months were used. In a second step all observations of decomposition were used independent of the length of the period for observation. To obtain a better fit between the abiotic functions and the observed decomposition an inertia

$$A(t) = d (D(t) - A(t-1)) + A(t-1) \quad (4)$$

where A denotes the adjusted abiotic function at the present day (t) or the preceeding day ($t-1$), d is the damping coefficient and D denotes the unadjusted abiotic function.

RESULTS AND DISCUSSION

General comments about the incubation of needle litter in the system

The litter-bags became throughgrown and overgrown with moss and cowberry shrub in the first half-year and were thus observed at a more shallow level in the profile than were single needles after the same time (Berg, 1977).

In our systems the litter-bags were big enough to allow free passage for the few animals in this system which influenced the process and they could thus exert their influence on decomposition rate. It appears, however, that their influence was so low that we may regard the present investigation as an evaluation of the microbial response only (Berg et al., 1980).

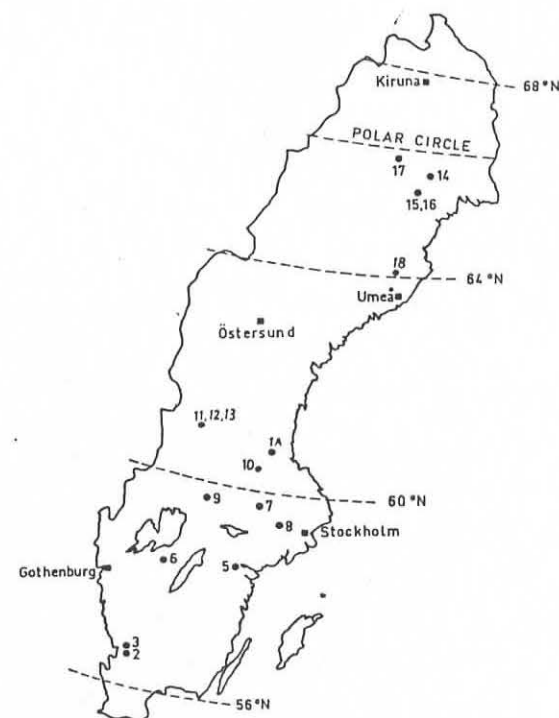


Figure 2. The approximate location of 17 different sites with Scots pine, Lodgepole pine, Norway spruce and birch forests where incubations were made with an unified Scots pine needle litter.

The regional AET approach

The unified Scots pine needle litter was incubated at the 18 sites along Sweden from the Polar circle to the southernmost part (Fig. 2). Of these 14 subsites had Scots pine forest, 8 Norway spruce, 4 subsites had Lodgepole pine and 2 birch forest (Table 2).

Table 2. Incubations of Scots pine needle litter in different forest types in an transect along Sweden. (cf the map in Fig 2).

Forest type	Incubations at sites no	No of sites
Scots pine forests	1A, 2, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 16, 18	14
Lodgepole pine forests	9, 11, 12, 13	4
Norway spruce forests	2, 3, 5, 6, 7, 8, 10, 17	8
Birch forests	3, 10	2

When analysing the weight loss data obtained versus climatic factors we made several attempts to relate weight loss not only to AET but also to other climatic element such as potential evapotranspiration, soil moisture deficit and precipitation. This work is not yet finished. We will therefore here discuss AET only and compare it to weight loss in the different forest types both separately and combined. We have also restricted ourselves to first-year weight loss values.

Table 3. Relations between actual evapotranspiration (AET) and first-year weight loss of a unified litter type incubated in Scots pine forest only (Eq 1), in all four forest types (Eq 2), in birch and Lodge pole pine forest (Eq 3), in Norway spruce forests only (Eq 4), in Scots pine, Lodgepole pine and birch forests (Eq 5).

Linear relation	Forest types
weight loss= $-27.55 + 0.1294$ (AET) $n=14$; $r=0.878$; $p<0.001$	Scots pine forests
weight loss= $3.13 + 0.057$ (AET) $n=28$; $r=0.495$; $p<0.01$	All four forest types
weight loss= $8.51 + 0.052$ (AET) $n=6$; $r=0.710$; n.s.	Lodge pole pine and birch forests
weight loss= $23.48 + 0.006$ (AET) $n=8$; $r=0.094$; n.s.	Norway spruce forests
weight loss= $-19.25 + 0.1115$ (AET) $n=20$; $r=0.834$; $p<0.001$	Scots pine, Lodgepole pine and birch forest

When thus comparing weight loss for this unified substrate incubated in Scots pine subsites to AET for the same time period ($n=14$: Table 3) we found a highly significant relation ($p<0.001$: Fig. 3). When using data from all sites ($n=28$) and thus including Norway spruce, Lodgepole pine and birch forest we still had a significant relation but on a lower level ($p<0.01$). In order to investigate whether there were different behaviours in different forest types we correlated AET to weight loss data from the Norway spruce forests but did not obtain a significant relation ($n=8$: $r=0.094$) (Fig 4). When combining the incubations in Scots pine, Lodgepole pine and birch forests we obtained a relation that was highly significant, though (Table 3) and it appears that AET is a better index for decomposition in the pine and birch forests than in the spruce forests. We may speculate that this may be due to the different characters of the canopy covers in these two different typers of forest.

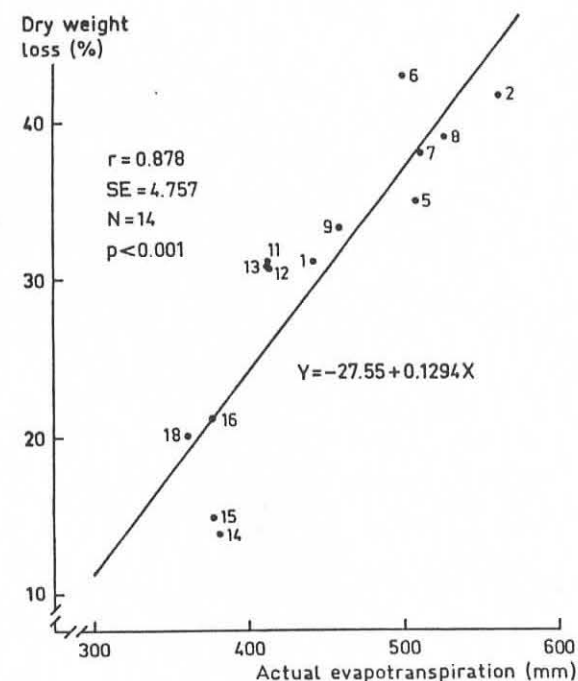


Figure 3. Relation between actual evapotranspiration and weight loss of an unified Scots pine needle litter incubated at 14 Scots pine forests sites in a transect along Sweden (cf Fig 2).

It appears that AET is a good index for the climatic effect on decomposition in the Scots pine forests and probably also in the Lodgepole pine and birch forests even if the data sets for these two latter types were small. AET as a climatic index on decomposition has, of course, some limitations and apart from spruce forests other limitations have been reported by Whitford *et al.*, (1981) who found the AET index less useful in desert system and in clear-cut forest areas.

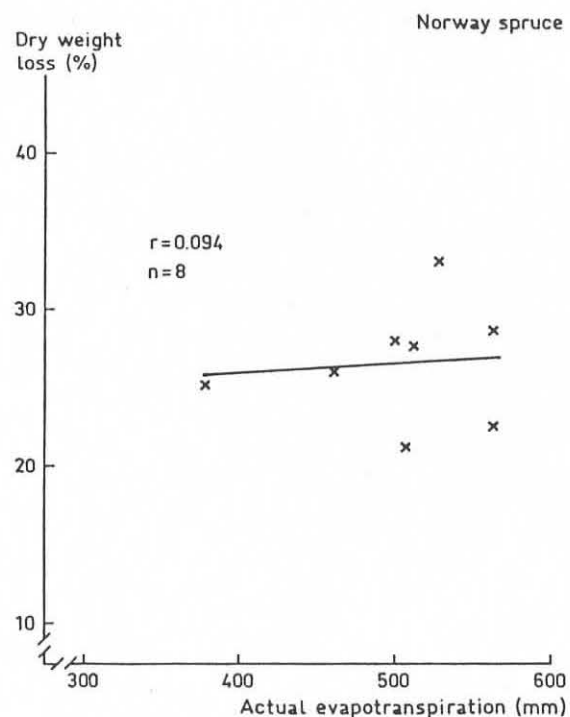


Figure 4. Relation between actual evapotranspiration and weight loss of an unified Scots pine needle litter incubated at 8 Norway spruce forest sites in a transect along Sweden (cf Table 1; Figure 2).

Even if we thus can distinguish differences between forest types we may also keep in mind differences in understory within one forest type which reflects different nutrient status and different hydrological properties of the soil (cf Table 1). We have thus in the Scots pine forests sites (studied here) two types of understory reflecting the different properties of the forest floor. A consequence of this may be best illustrated by the results obtained

from sites 15 and 16 which are located about 100 m from each other on flat ground. The former site has lichens and cowberry (*Vaccinium vitis-idaea*) as understory and the latter mosses and blueberry shrubs (*V. myrtillus*). Both have the same AET value in our analysis but there was a considerable difference in weight loss with 14.7 at the poor site and 21.2 at the richer site. It is thus possible that with a careful selection of sites the presented relation may be improved and an attempt has been made to do this.

The local, soil climate model approach

In a first attempt to relate climate and decomposition we used only weight loss data which were significantly different which in practice means that only weight losses for periods longer than 145 days were used. These were related to climate by linear regression. In the equations (1) to (3) different values of the parameters Q_{10} , θ_0 , a , ψ_0 and b were used to obtain the best coefficient of determination for the linear regressions where soil climate was treated as independent variable. The two different relations obtained for the first and for the second incubation year respectively were never significantly different neither with respect to slope or level. Nevertheless it was quite obvious that for all different abiotic measure they were better related to the decomposition of the second year than to the first-year weight losses.

When the best linear relationships for the first and the second incubation year were used separately a good agreement was obtained between predicted and observed decomposition (Fig 5). The agreement was better for the second incubation year than for the first. The sensitivity of the coefficient of determination for different choices of values on Q_{10} , θ_0 and a showed that the best correlation was obtained with a low value on Q_{10} , namely 1.3.

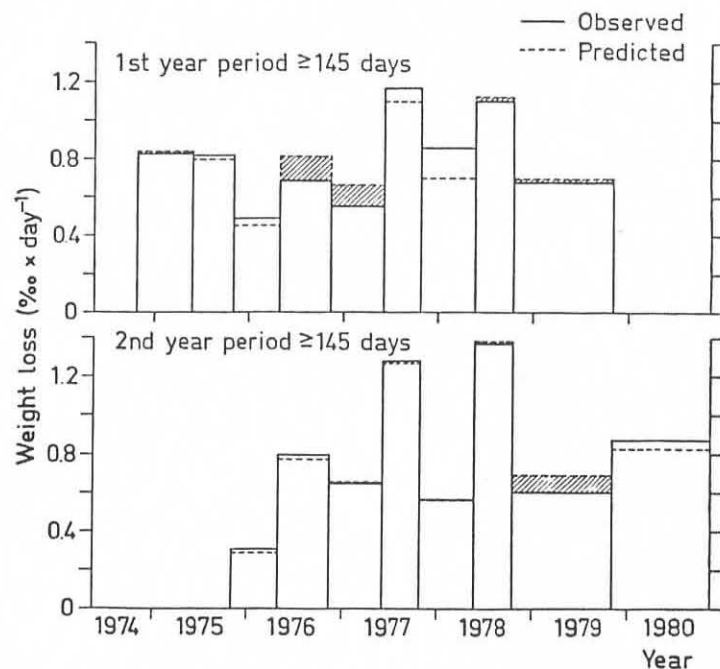


Figure 5. Observed decomposition rates for periods longer than 145 days for both the first and the second year of decomposition compared with predicted litter weight loss. The empirical coefficients estimated from the same data. Shaded area shows overestimated weight loss.

When all the decomposition periods were used independently of period length to test the validity of their parameter values obtained from the same decomposition material but from which short periods were excluded a very poor relation was obtained between predicted and observed weight loss (Fig 6). This was emphasized for the first year of decomposition where the number of periods observed increased from 9 to 15. The coefficient of determination (r^2) decreased from 0.84 to 0.10 which means that the latter was not significantly different from zero. A typical pattern here was overestimation of the decomposition in the beginning of the growing season and an underestimation in the late autumn which suggested a lag in the climatic effect on decomposition. When an inertia equation (4) was introduced with

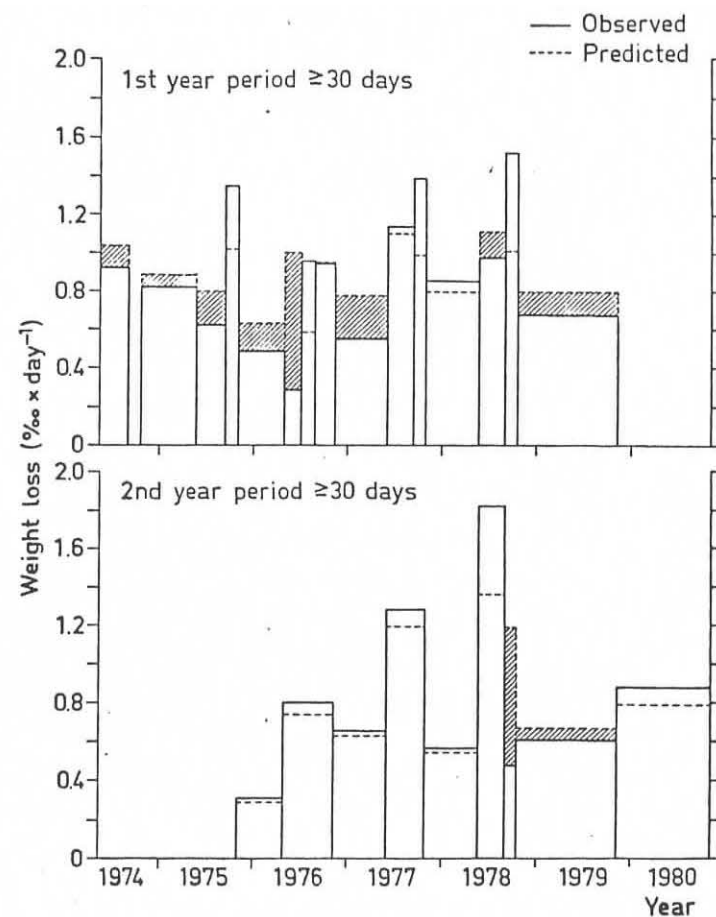


Figure 6. Observed decomposition rates for all available observational periods for both the first and the second year of decomposition compared with predicted litter weight loss. The empirical coefficients estimated without inertia in the abiotic functions. Shaded area shows overestimated.

different values on the damping coefficient d a substantial improvement of the linear regression was obtained especially if the Q_{10} value also was changed to higher values for example from 1.3 to 3.1 (Fig 7). The highest values of the coefficient of determination were obtained with a d -value of 0.015 giving a time constant of approximately 3 months of the system.

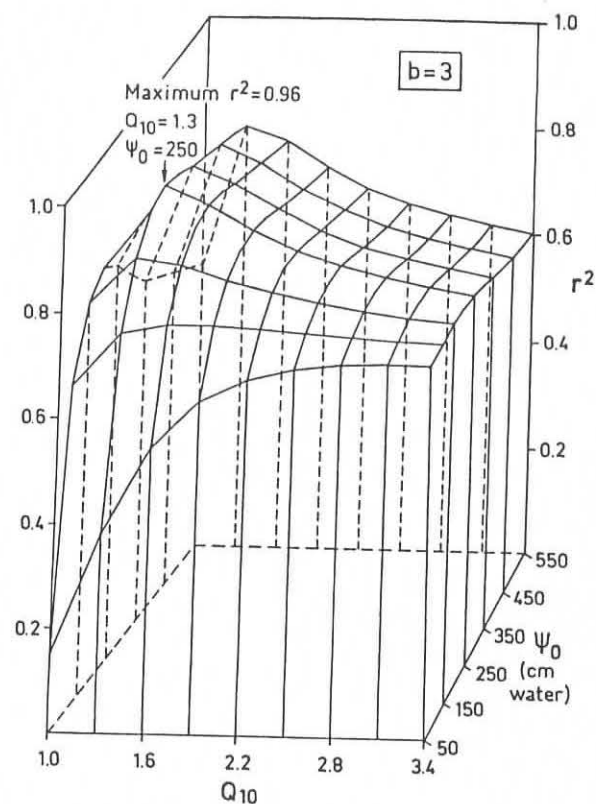


Figure 7. Coefficients of determination (r^2) obtained with linear regression between weight losses from the first year using all available observations and the product of equations (1) and (3) reflecting water tension in combination with the inertia equation (4) for different values of the damping coefficient $\underline{d}$ and Q_{10} .

DISCUSSION

Both the AET and the SCM approach have been found useful when analysing temporal or special variation of litter decomposition rates. The AET approach requires a minimum of climatic data and no specific information on stand and soil properties which makes it attractive for practical use. The SCM approach on the other hand requires in theory a substantial amount of information on properties which are seldom available for forest sites in general. However, both methods make use of the same fundamental climatic

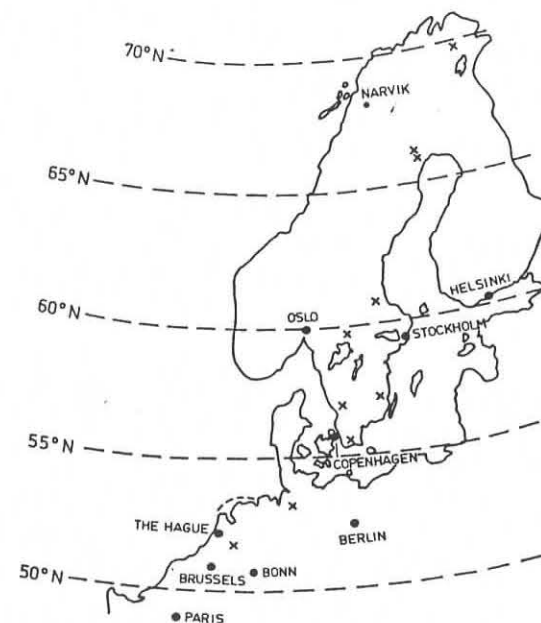


Figure 8. The approximate location of ten sites in a north European transect with Scots pine forest on sediment soil where incubations of Scots pine needle litter are made.

variables and they could thus be applied together. When the two approaches were compared for analysing temporal variation on one site better resolving was found to the SCM approach. This could in part be explained by the fact that the SCM approach accounts for different conditions during the winter (frost, temperature, availability of unfrozen water) whereas the AET approach mainly accounts for differences in summer conditions.

In an ongoing work both approaches will be used to analyse temporal and special variation of litter decomposition from a type of forest which could be found in a long transect, namely Scots pine forest on sediment. The transect selected thus has sites with the approximate locations given in Fig 8 and goes from about 70°N in northern Finland down to about 52°N in southern Holland. At the seven northernmost sites lichens and cowberry dominate as understory whereas in the three southernmost ones grass is dominating on the ground. The first incubation of unified litter took place in 1981, another incubation was made in 1982 and a third will be made in 1983. Samplings have so far been made only once a year and we intended primarily to analyse the weight loss data in the same way as was done with the first transect namely versus AET.

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